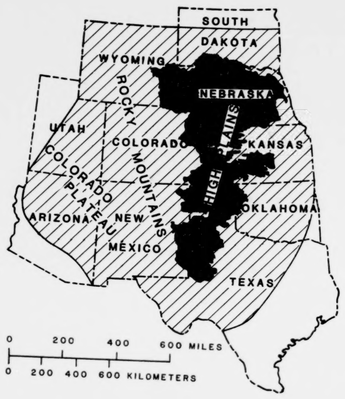
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY



EXPLANATION

STUDY AREA

AREA OF THE HIGH PLAINS AQUIFER

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INTRODUCTION

The principal map shows geologic structures and lineaments that indicate fracture traces in sedimentary rocks in all or parts of Arizona, Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, Utah, and Wyoming. Fractures associated with geologic structures and lineaments may affect the potential fracture permeability of consolidated rocks. Divisions indicating differences in the potential fracture permeability are delineated on the map.

The map was prepared as part of the U.S. Geological Survey's High Plains Regional Aquifer System Analysis (RASA). The objectives of the High Plains RASA are to describe the quantity and quality of the water resources of the High Plains aquifer and to develop the means to evaluate regional aquifer response to changes in ground-water development (Weeks, 1978, p. 2-3). The small map shows the area of the High Plains aquifer in relation to the area described in this report. A similar map has been prepared for the Northern Great Plains area covering most of Montana, North Dakota, South Dakota, Wyoming, and northern Nebraska (Cooley, 1985).

Fractures, consisting of joints and faults, affect the hydrologic regime of many aquifers throughout the Rocky Mountains-High Plains region. Fracture traces in rocks such as limestone, dolomite, and fine-grained sandstone are important because fracture traces can be used to help assess the potential capability of the rocks to transmit water. Springs, for example, commonly occur along joints, bedding planes, and faults. However, in a given area the mapped fractures may or may not be related to fracture (secondary) permeability, which is dependent on the size of the fracture openings and the extent to which the fractures are interconnected.

The density of fractures and their effect on potential fracture permeability are greatest along the main fault and fold structural features and along or near intersections of lineaments (Lueder and Simons, 1962; Moore, 1976). Geologic investigations indicate that sedimentary rocks are more extensively fractured or contain more open fractures along faults and fold structures such as uplifts, anticlines, domes, and monoclines. Sedimentary rocks are less fractured in synclines and in areas where the strata are nearly horizontal. Lineaments also are important in determining areas having concentrations of fracture traces, particularly in areas containing only gentle structures.

PRINCIPAL STRUCTURAL FEATURES USED IN DETERMINING DISTRIBUTION OF FRACTURE TRACES

Geologic structure provides a basis for determining the distribution of fracture traces. A tectonic map of the United States (U.S. Geological Survey and American Association of Petroleum Geologists, 1961) provided the structural base for this study. The tectonic map delineates structurally uplifted areas, structurally downwarped areas, and monoclinal areas having relatively steep-dipping strata, as indicated by close spacing of the structure-contour lines. In general, the uplifted and monoclinal areas are more extensively deformed (and fractured) than are the basins; the uplifted and monoclinal areas were the primary basis for determining the divisions of fracture traces shown on the map.

The rocks of the Rocky Mountains region (including the Colorado Plateau) have been involved with much more extensive structural deformation--uplift, faulting with some thrust faulting, and folding--and are more extensively fractured than the rocks of Pennsylvanian to Tertiary age at or near the land surface in the High Plains. Many structures in the High Plains area, such as the Anadarko basin (Texas Panhandle and western Oklahoma), Chadron arch (northwestern Nebraska), and Nemaha uplift (eastern Kansas), were formed before deposition of Pennsylvanian and younger rocks. In contrast, the main movements that formed the structures of the Rocky Mountains region are more recent and have affected rocks as recent as Tertiary. Locally, differential structural movement is as recent as Quaternary.

The assessment of potential fracture permeability included interpretation of lineaments that occur as straight or slightly curved lines on the Earth's surface. Lineaments were used as secondary features in determining the division boundaries shown on the map. The lineaments shown on the map are not identified as to type or origin, although most probably represent fractures (joints or faults) or fracture zones. Most are believed to be the surface expression of fractures or fracture zones that extend upwards from zones of structural weakness in the Precambrian basement rocks--a conclusion also suggested by Friedman and Simpson (1978, p. 27, 29) from a lineament study of part of the Paradox basin (eastern Colorado Plateau).

The lineaments shown on the map were plotted from a mosaic of Landsat imagery with a scale of 1:5,000,000 (U.S. Soil Conservation Service, 1974). At that scale, only the principal lineaments were recognized and are shown on the map. Physiographic features are used chiefly to identify the lineaments. These include straight segments of escarpments, ridges, canyons, and valleys. Vegetation growing on flood plains accentuates the configuration of shallow valleys in areas of low relief. In plains areas having slight local relief, contrasts in tonal patterns indicating differences in vegetation, soils, or outcropping rocks helped in the recognition or extension of some of the lineaments.

Other lineaments that aided this study, but are not shown on the map, were determined from visual inspection of false-color infrared composites of Landsat imagery at a scale of 1:500,000 for western Kansas (Cooley, 1984b), South Dakota and northern Nebraska (Cooley, 1983a), the Texas and Oklahoma Panhandles (Cooley, 1984c), southwestern Utah (Cooley, 1984a), and Wyoming (Cooley, 1983b). Also used were lineament maps by Friedman and Simpson (1978, pl. 1) for a small part of the Colorado Plateau area, and by Finley and Gustavson (1981, pl. 1) for the Texas Panhandle.

Thick, mobile salt deposits influence fracture permeability in large parts of the High Plains and in the Colorado Plateau, where movement and solution of the salt deposits has increased fracturing in the overlying rocks. Salt solution also has assisted in the formation of sink holes, internally drained depressions, and some lowlands, of which some are associated with tectonic features (Bachman and Johnson, 1973). The principal salt deposits that at least locally strongly influence fracture permeability underlie much of the southern High Plains and parts of northeastern Arizona, eastern Utah, and western Colorado. In the High Plains, effects of solution of the salt deposits on fracture permeability extend from western Texas to as far north as central Kansas. The generally deeply buried and relatively thin salt deposits in other parts of the Rocky Mountains-High Plains region seem to have little affected the fracture permeability in the overlying rocks.

DIVISIONS OF FRACTURES THAT MAY AFFECT POTENTIAL FRACTURE PERMEABILITY

The five divisions shown on the map represent a classification of fracture traces in sedimentary rocks according to how the traces might affect the secondary permeability of the rocks. The range is from division 1, representing fractures judged to have the least potential fracture permeability, through division 5, judged to have the greatest. The judgement of potential fracture opening and density was based on (in order of importance): (1) The distribution of structures shown on the tectonic map of the United States (U.S. Geological Survey and American Association of Petroleum Geologists, 1961); (2) lineaments; and (3) local effects of solution and movement of thick deposits of salt. A description of the general location and structural features for each of the divisions is given in the map explanation.

The delineation of the divisions on the map was influenced by considering the effects of the Late Cretaceous and younger tectonic activity in the Rocky Mountains and adjacent areas. The Rocky Mountains area (mainly divisions 3 through 5) was moderately to substantially affected, whereas most of the High Plains (mainly divisions 1 and 2) was affected only slightly. Only the part of the High Plains areas adjacent to the Rocky Mountains was affected appreciably by this tectonic activity. The effects of buried structures (formed before Pennsylvanian time) were considered to be minimal in the Pennsylvanian and younger rocks that underlie most of the High Plains.

West of the High Plains the potential fracture permeability is classified as being in division 3 or greater. In many places the rocks of the Rocky Mountains have been uplifted or extensively folded and faulted; generally these areas were classified as division 5. The basins of the Rocky Mountains region were classified as division 3, in comparison with the uplifts and arches of the High Plains, classified principally as division 2 and subordinately as division 3. Areas mainly in transitional structural positions, between the uplifted areas and the basins, generally were assigned the intermediate classification, division 4.

Many of the division boundaries are located along conspicuous lineaments. Lineaments also are used more extensively in determining the extent of the divisions within the High Plains area than in the Rocky Mountains area. Although the distribution and concentration of the lineaments locally may affect the potential fracture permeability in all divisions, this relationship is believed generally to be more significant in divisions 1 through 3 than in divisions 4 and 5.

The presence of mobile salt deposits that have increased the fracturing in the overlying rocks influenced the delineation of the divisions of potential fracture permeability. The eastward extension of division 3 in southeastern New Mexico and in the nearby parts of Texas was based principally on the presence of salt structures and in conjunction with the distribution of lineaments. Similarly, the extension of division 5 in areas affected by the salt deposits in the Colorado Plateau is based partly on the distribution of fractures caused by mobile salt deposits.

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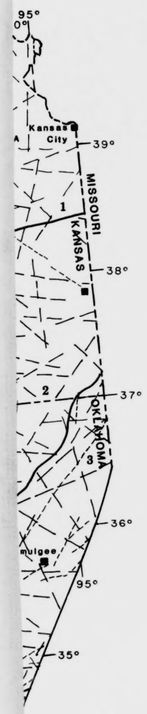
CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
foot	0.3048	meter
mile	1.609	kilometer



EXPLANATION

DIVISION OF FRACTURE TRACES IN SEDIMENTARY ROCKS--Rocks mainly of Tertiary to Cambrian age in the Rocky Mountains area and rocks mainly of Pennsylvanian or younger age in the High Plains area. A few small areas of Precambrian sedimentary rocks also are included in Arizona. The divisions are classified from division 1 (areas with fractures that may have the smallest effect on fracture permeability) through division 5 (areas with fractures that may have the largest effect), judged on the basis of the type and distribution of fold and fault structures, the distribution of linear features, and the presence of generally deeply buried salt deposits

1 — Division 1--Mainly Pennsylvanian and younger rocks of the High Plains area, extending from Nebraska to northern Texas and occupying parts of large, shallow basins between buried low uplifts and arches

2 — Division 2--Mainly Pennsylvanian and younger rocks of the High Plains area, extending from South Dakota to Texas and occupying the areas of buried uplifts and arches and broad flanks of some basins. Because most of the structures were formed before the Pennsylvanian and younger rocks were deposited, the structures generally have had only a slight effect on fracturing in the overlying rocks

3 — Division 3--Rocks mainly in the structurally low areas of the Rocky Mountains, Colorado Plateau, western High Plains; and in low structural highlands of Texas, southeastern Oklahoma, and central Nebraska. The rocks generally occupy the central area of basins, broad synclinal areas, and the foreland of the mountains, except in the High Plains where they are on some of the arches and uplifts

4 — Division 4--Rocks of the Rocky Mountains, Colorado Plateau, and western High

VOLCANIC ROCKS OF CENOZOIC TO MESOZOIC AGE--Sedimentary rocks beneath volcanic rocks may have potential fracture permeability similar to that of nearby exposed sedimentary rocks. Not classified for potential fracture permeability

GENERALLY STRONGLY FRACTURED IGNEOUS AND METAMORPHIC BASEMENT ROCKS OF CENOZOIC TO MESOZOIC AND PRECAMBRIAN AGE--Not classified for potential fracture permeability

CENTER OF VOLCANIC ERUPTION--The rocks generally are more strongly fractured near the centers of volcanic eruption and dikes than in areas away from the volcanics. In some locations, fractures may be filled by rock material associated with volcanism, and therefore have a smaller potential fracture permeability than would be expected on the basis of the number of fractures alone

VOLCANIC DIKE

GEOLOGIC CONTACT

DIRECTION OF DIP AND STRIKE OF SEDIMENTARY ROCKS--Determined mainly from the close spacing of structure contours shown on tectonic map (U.S. Geological Survey and American Association of Petroleum Geologists, 1961). Rocks near the strike and dip symbols generally are more strongly fractured than the rocks located away from the symbols

AREA WHERE SALT IS PRESENT OR WHERE REMOVAL OF SALT BY SOLUTION HAS AFFECTED THE STRUCTURE IN OVERLYING ROCKS--Mainly the large area extending from western

For additional information write to:

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P.O. Box 1125
Cheyenne, Wyoming 82003

Copies of this map can be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
(Telephone: (303) 236-7476)

Base from Tectonic Map of the United States (U.S. Geological Survey and American Association of Petroleum Geologists, 1961)

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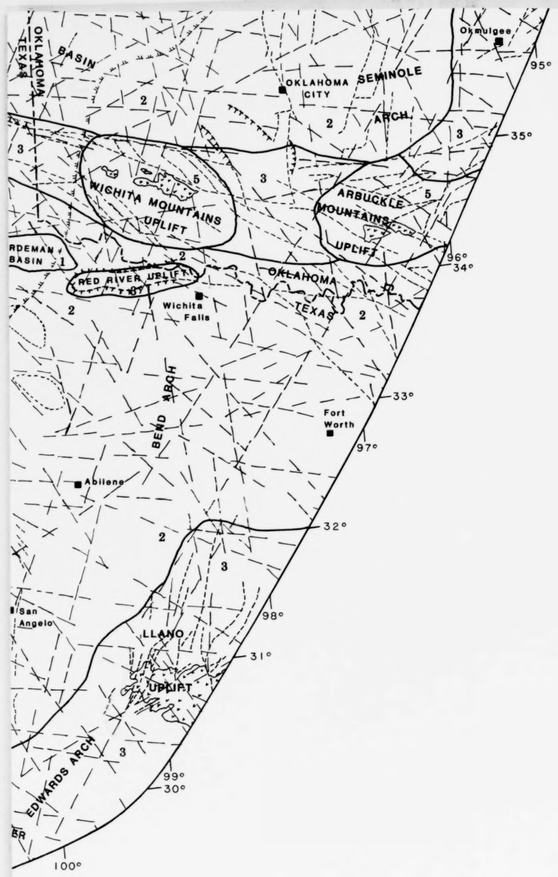
DIVISIONS OF POTENTIAL FRACTURE PERMEABILITY, BASED ON DISTRIBUTION OF STRUCTURES AND LINEAMENTS,

By

Maurice E. Cooley

1986



outcropping rocks helped in the recognition or extension of some of the lineaments.

States, exclusive of Alaska and Hawaii: U.S. Geological Survey map, scale 1:2,500,000, 2 sheets.

EXPLANATION

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4 — Division 4--Rocks of the Rocky Mountains, Colorado Plateau, and western High Plains. The rocks generally occupy intermediate structural positions--arches, platforms, and anticlines between the basins (division 3) and the uplifts (division 5)

5 — Division 5--Rocks occupying the structural highlands of the Rocky Mountains, Colorado Plateau, and small uplifted areas in southern and southeastern Oklahoma. The rocks generally are in areas of highest uplifts and along major anticlines

Division Boundary

Area in divisions 1 through 3, determined mainly from the distribution of lineaments, judged to have less potential fracture permeability than the rest of the area in the division

Czp€ — GENERALLY STRONGLY FRACTURED SEDIMENTARY ROCKS OF CENOZOIC TO PRECAMBRIAN AGE--Thick valley-fill deposits of intermontaine basins and extremely fractured rocks in other basins and in nearby mountain ranges, mostly in Arizona, Colorado, New Mexico, and Utah; also the tightly folded and faulted rocks of the Overthrust Belt of southwestern Wyoming and northern Utah. Not classified for potential fracture permeability

VOLCANIC ROCKS OF CENOZOIC TO MESOZOIC AGE--Sedimentary rocks beneath volcanic rocks may have potential fracture permeability similar to that of nearby exposed sedimentary rocks. Not classified for potential fracture permeability

GENERALLY STRONGLY FRACTURED IGNEOUS AND METAMORPHIC BASEMENT ROCKS OF CENOZOIC TO MESOZOIC AND PRECAMBRIAN AGE--Not classified for potential fracture permeability

CENTER OF VOLCANIC ERUPTION--The rocks generally are more strongly fractured near the centers of volcanic eruption and dikes than in areas away from the volcanics. In some locations, fractures may be filled by rock material associated with volcanism, and therefore have a smaller potential fracture permeability than would be expected on the basis of the number of fractures alone

VOLCANIC DIKE

GEOLOGIC CONTACT

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AREA WHERE SALT IS PRESENT OR WHERE REMOVAL OF SALT BY SOLUTION HAS AFFECTED THE STRUCTURE IN OVERLYING ROCKS--Mainly the large area extending from western Texas to central Kansas, and smaller areas in northeastern Arizona, southeastern Utah, and southwestern Colorado. The movement and removal of the salt by solution has increased local fracturing in the overlying rocks

AREA OF SAND DUNES--Northwestern Nebraska and southern South Dakota (from Gutentag and Weeks, 1980). The dune sand, 300 feet thick in places, marks many of the lineaments present in the underlying rocks

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FAULT--Rocks adjacent to faults generally are more strongly fractured than rocks in areas away from faults

LINEAMENT--Determined from mosaic of Landsat imagery (U.S. Soil Conservation Service, 1974). Potential fracture permeability is judged to be greater along or near the intersections of lineaments than elsewhere

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Geology from U.S. Geological Survey and American Association of Petroleum Geologists (1961) and Bayley and Muelberger (1968). Lineaments by M.E. Cooley, 1980

RIBUTION OF STRUCTURES AND LINEAMENTS, IN SEDIMENTARY ROCKS OF THE ROCKY MOUNTAINS-HIGH PLAINS REGION, WESTERN UNITED STATES

By

Maurice E. Cooley

1986